FIRE RISK EVALUATION PROCESS CONSIDERATIONS

STRATEGIC ANALYSIS OF COMMUNITY RISK REDUCTION

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ABSTRACT

This research project took the first steps to evaluate the extent or depth of analysis needed in a fire hazard or risk assessment process. The values or elements that should be considered in the assessment, the amount of effort that such an assessment should entail were explored.

This research employed both historical and action research to (1) determine if an exacting, quantitative fire risk analysis method should be utilized to evaluate fire hazards presented by structures and facilities, (2) to determine what elements or values of fire risks must be examined to compile the data necessary to make quantitative risk analyses, and (3) to determine the amount of effort that would be required to make a quantitative risk analysis productive in a structure by structure assessment program.

The primary research procedure utilized evaluated sources seeking the present technical data and information related to fire risk assessment. The data compiled assembled three primary elements and a significant list of sub-elements or values which must be included in a assessment process. Appendices were assembled to consolidate some of the data into groups so that the true magnitude of the necessary analysis could be visualized.

This research concluded that though analytically computable fire risk impact values could be determined with today's technology and mathematical processes, the resource demand upon most fire agencies would be beyond their capabilities. The conclusions also continue to support the need for such an analytical capability through another process.

The recommendations coming from this research include (a) a continued effort to develop a means to accurately and with validity achieve fire risk assessment of buildings and facilities, (b) utilize the fire risk assessments process elements determined within the present capabilities of fire service organizations to improve data collection and with the objective to aid services such as fire prevention inspections, new construction plan review, and pre-plan efforts for fire suppression forces, as well as future fire risk assessment efforts and (c) attempt to achieve such quantitative analysis efforts through fire protection engineering services for newly constructed buildings - funded by the owner or developer.

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INTRODUCTION

The Brighton Fire Protection District, as with most governmental agencies, is experiencing a changing tax payer sentiment. Taxpayers today are wanting to scrutinize the services offered by governmental agencies and be selective about which to support and at what economic level. Traditional fire services are not a daily need and are coming under watchful consideration.

To respond, the Brighton Fire Protection District (BFPD) must examine closely every service area presently provided and evaluate the best manner to efficiently continue to offer those services. Fire suppression is still the paramount service offered by fire departments and yet is becoming the least continuously utilized service. To maintain the needed public support for fire suppression, fire agencies must demonstrate quality operations with the most efficient usage of taxpayer dollars. Fire suppression service efficiency can only be developed through careful matching of suppression capabilities and the fire hazards or risks within the protection area. To accurately assess fire hazards or risks, providing the foundation upon which suppression capabilities can be determined, is essential.

The District's demographic make-up constantly changes, the fire hazards or risks change with age, grow in numbers, or become more varied in nature; adding greatly to the value of an assessment ability as well as the complicacy of that assessment process.

The purpose of this research was to take the first step to evaluate the extent or depth of analysis needed in an assessment process, the values or elements that should be considered in the assessment, and the amount of effort that such an assessment could or should demand. Utilizing this research as the foundation, the final goal is to actually develop such anassessment tool and process.

Historical and action research methods were employed to answer the following questions and gain the foundation information.

1. Should an exacting, quantitative fire risk analysis method be utilized to evaluate fire hazards presented by structures and facilities?

2. What elements or values of fire risks must be examined to compile the data necessary to make a quantitative risk analysis?

3. What amount of effort would be required to make a quantitative risk analysis productive in a structure by structure assessment program?

BACKGROUND AND SIGNIFICANCE

The Brighton Fire Protection District covers approximately 180 square miles of area located on the front range of the Rocky Mountains of Colorado. The District is directly adjacent to the newly completed and rapidly developing Denver International Airport (DIA) complex; northeast of the city of Denver. This region is recognized as one of the most rapidly growth areas within the state and nation.

Annual growth rates are now reaching the 8 to 10 percent pace with build-out far in the future. Demographic development continues greatest in areas of single and multi-family residential occupancies. Support or service - commercial occupancies, assembly occupancies, light to moderate industrial facilities, and spotted impacts of heavy industry and high rise structures are increasing rapidly.

Newly created tax referendums, applying to property and sales taxes, have greatly limited the income growth potentials of most government services within the state. In fact, even though the tax revenues generated by the growth now being experienced cannot be taken advantage of without passage of special election referendums allowing such revenue usage. Some limited increases in revenues are provided for but must remain within a very specific guidelines and presently are not keeping up with service growth demands. Reaching the efficiencies noted within the Introduction of this report is absolutely essential if existing fire service levels are to be appropriately maintained.

BFPD, within the limits of the present revenue conditions, participates in most of the traditional fire prevention efforts toward code enforcement, community planning, public education, and hazard mitigation programs; all in an effort to prevent fires as well as true attempt to maintain fire hazards or risks within the abilities of District fire suppression forces. Yet, as inmost other fire districts, fires continue to occur.

New approaches to fire prevention code enforcement are adopting performance based code processes rather than traditional prescriptive type codes. This new enforcement alternative may provide the needed alternatives to accomplish the next level of fire safety in buildings but both enforcement methods continue to make focus on post ignition - fire containment and do not appear to strongly consider the fire ignition source potentials.

Australia has established new efforts toward building or fire code enforcement utilizing a performance based approach with the newly published Fire Engineering Guidelines. Unlike many of the performance based code efforts in the U.S., the Australian effort has based the building's performance requirements on a risk or hazard assessment. As noted in the Forward,

"Fire safety involves control of risk to life and often to property. Without appropriate risk-assessment methodology, it is impossible to quantify risk or compare alternative design solutions. ...

Risk assessment methodology has been successfully applied in regulations for catastrophic events such as earthquakes and extreme winds, and fire risk can be similarly predicted (1996)."

Additionally, the Australian guidelines require consideration of local fire suppression capabilities and such considerations as response times, rescue time requirements, and time considerations to mount a fire attack and accomplish extinguishment. Unfortunately the Australian effort provides only the criteria for risk or hazard analysis but does not provide an actual analysis schedule or means of rating the potentials for fire.

U.S. fire service related industries, most specifically theNational Fire Protection Association (NFPA), have for many years made standards available to the fire service in an effort to guide improvements in areas of performance and operations. National Fire Protection Association Standards, specifically NFPA 1201 - *Standard for Developing Fire Protection Services for the Public* (1995) and the yet to be published NFPA 1200 - *Standard for Organization, Operation, Deployment, and Evaluation of Public Fire Protection and Emergency Medical Services* (Draft), make fire hazard or risk analysis, evaluation, and risk management an mandatory requirement for compliance with the Standards.

Compliance with the NFPA Standards is intended to indicate positive performance by the agency providing the fire services. These Standards establish the need for analysis but as with the Australian effort, do not provide a method or means to accomplish the analysis.

The International Fire Chiefs, through their National Fire Service Accreditation Program, have recently created an internal industry effort to generate a nationally recognizable standard for measurement of performance for the fire service. Within the newly published <u>Fire and Emergency Service Self Assessment Manual</u>, fire risk assessment and the usage of the assessment information for determining performance coverage levels is a performance evaluation indicator (p.4-5). A positive outcome of the performance evaluation indicators leads to National Accreditation of a fire service organization. Many fire service organizations hope this National Accreditation will indicate to tax payers and protected area citizens that the efficiency indicated within the Introduction of this research report has been achieved. Again, the risk or hazard analysis is required but the analysis process is not created.

Private industry, predominately the chemical companies and to some extent the insurance industry, have spent significant resources on establishing fire risk or hazard analysis guidelines. Fire protection engineers have made significant strides in fire risk analysis efforts and from those efforts have created computerized fire models to analyze fire development and growth scenarios. Much of this work is very industry or scope specific and does not reach the needs outlined by this Background and Significance review. The analysis approach viewed necessary by this review must examine the building or facility from the potential for fire to the actual fire control producing some conclusive elements which can be utilized as a fire suppression force capability determination means and as a new initiation effort for fire prevention activities.

LITERATURE REVIEW

Defining Fire Risk or Hazard Analysis

In the mid to late 1980's and early 1990's, the National Academy offered a fire management course "Fire Risk Analysis: A Systems Approach." The Student Manual, Published in 1984,provides a brief discussion of the value of fire risk analysis and a simplified definition of fire risk as "the potential vulnerability to fire with the possibility of loss, injury, disadvantage or destruction (p.3-4)." The manual identifies several elements of risk which must be analyzed to determine the full impact; those elements span a scope of questions from when and why the fire might occur, to where and what is in danger, and what the impacts might be imposed on the responding agencies and the resulting community losses.

Several authors studied introduce many different yet specific thoughts of risk and hazard analysis, including terminology. John R. Hall (Fire Protection Handbook), 1997), becomes specific about the elements of fire risk analysis and divides it into two areas of consideration; severity, considering also a means of measuring the severity, and probability for fire (p.11-78). Hall contends that efforts toward target hazard identification or fire flow calculations are not risk analysis because of the lack of fire probability and uncertainty considerations and should be considered hazard analysis. Richard Bukowski, (Fire Protection Handbook, 1997) supports Hall's comments and contends that hazard analysis is more concerned with determining what should be expected from specific conditions in a fire scenario (p.11-70).

W.D. Rowe, in a 1982 paper presented at an ASTM symposium, introduced the term "risk assessment" which by his definition covers determination of risks and the social considerations of risk (p.5). Rowe explains the social considerations as whether the potential of loss is worth the risk or the costs to prevent the risks are in excess of the loss. Rowe contends this is the total process of risk analysis (p.5).

Marita Kersken-Bradly, in a Chapter contribution to the Handbook of Fire Protection Engineering (1992), indicates that risk assessment have referred to point schemes, schedules, fire safety matrices, construction of probability curves, evaluation of risk indices as methods of evaluation in the past. Logic tree analysis is appearing to gain popularity and gradual usage (p.4-1). Kersken-Bradley indicates that these methods general evaluate fire scenario elements from ignition, through fire development, to termination - considering even elements of self-termination and includes impacts of fire fighter intervention (p.4-2,-,4-7).

As with Hall and Bukowski, H.J. Roux (1982) appears to not consider fire risk or hazard analysis to be one in the same and provide a single definition for this process. Roux quotes the American Society for Testing and Materials' (ASTM) definition of risk as "as the probability that a fire will occur and the potential for harm to life and damage to property resulting from its occurrence (p.20)." Roux defines hazard from the point of view that any risk that is above an acceptable level by the authority having that decision power, is a hazard.

Key Elements of Fire Risk Assessment

The National Fire Academy (NFA) course "Fire Risk Analysis: A Systems Approach" (1984) provided several elements which should be considered in determining the risks. Those elements specifically listed in the Student Manual are;

1. When might the incident occur?
2. Why would the incident occur?
3. Who is in danger?
4. What is in danger?
5. Where is the danger?
6. Where will the loss be?
7. Why will this Fire Dept. have problem (p.3-5)?

Rowe (1982) lists five steps to the process of risk assessment. Those five steps are;

1. Identify causative events. These causative events may lead to several possible outcomes.
2. Define the outcomes noted in item 1 and their relative probability should be determined.
3. Define exposure pathways, the means by which risks area transmitted.
4. Define the possible consequences of risk exposure, and determine, for each risk, the probability that consequences will occur.
5. Consider the value placed by affected individuals on the consequences of risk exposure (p.9 & 10).

Rowe expands the consequences area of the five elements to discuss outcomes and mitigation efforts for those consequences. The mitigation efforts might include fire fighting methods and equipment, rescue and medical systems, and such other items as insurance for spreading risks, and loans for recovery purposes(p.10).

Kersken-Bradley (1992) indicated the usage of logic tree concepts in risk assessment is growing in popularity (p.4-1). In the mid 1980's, the National Fire Protection Association

(NFPA) organized a to develop a fire safety committee that eventually developed a logic tree system for fire safety in structures; the "Fire Safety Decision Tree." The now published "Safety Concept Tree" presents a very large majority of the main elements of risk assessment listed by other authors but also presents an even greater detailed list of sub-components. The "Safety Concept Tree" is duplicated in Appendix A. The safety tree considers the two primary objectives in building fire safety as being prevention of ignition and management of the fire impact. These two objectives are further sub-divided into five additional considerations; control of heat energy sources, control of energy-source interaction, control of fuels, management of the fire, and manage the exposed. From this level, the objectives are further broken down into a significant list of additions considerations from each of these five elements. This is perhaps the most complete list of fire assessment consideration found in this research (NFPA 550, 1995, p.550-4 - 550-8).

The 1986 research project, *The National Fire Risk Assessment Research Project,* concluded "the likelihood that fire will occur and the severity, or hazard, of the incidence once it occurs" were identified as the two primary components of fire risk (National Fire Protection Research Foundation, p.I-1).

Though this project was intended to develop a method of correlating fire losses of specific products with the fire properties of the product, elements of fire risk were utilized in the procedures of the research. Other sub-components of fire risk discussed in the report were ignition sources or origins, fire growth and the impact of construction types, ventilation sources and impacts, flame spread and fire growth (p.I-5,I-12).

A member of the Swiss Fire Prevention Service, M. Gretener began studying an arithmetic approach to fire risk evaluation in the 1960's. The components utilized in what is now referred to as the "Gretener Method" were primarily the probability of ignition and the probable severity of the fire. The severity component was further divided into the potential hazard, which deals with the building contents and building construction, and the fire protection methods, which deals with the building's fire resistivity and fire suppression equipment or processes (Watts, 1992, p.4-91).

The insurance industry has utilized risk evaluation schedules for many years to determine insurance coverage rates. Though these are not utilized in a manner consistent with the intent of this research, they do present some elements which should be considered. The Insurance Services Office (ISO) *Commercial Fire Rating Schedule - Survey* evaluates elements dealing with the occupancy usage and contents, building construction, fire development passageways, internal protection, and external exposure of other structures. Ignition is somewhat evaluated through historical fire data pertaining to specific occupancy usages (Watts, 1992, p.4-91 & 4-92).

From the ASTM definition of risk quoted by Roux (1982), the key elements of risk assessment is the probability for ignition, potential for harm to life and property.

Methods for Evaluating Key Assessment Elements

From the key elements of fire risk research, the most consistent elements of assessment appear to fit into three primary groups, (1) ignition or the probability for ignition, (2) fire development or exposure pathways, and (3) the impact of the consequences of the fire, once developed. To properly evaluate the three groups, each will obviously have to be broken down into smaller individual elements. To reach the primary objective of this research, the group dealing with consequences of the fire must consider the impact on response forces and their capabilities.

There are likely several different methods of evaluating or assessing fire risks or risk elements. Watts contends that there are four classifications of assessment methods, narratives, checklists, schedules, and theoretical methods. Narratives are best described by the fire codes that are in existence today; providing explanations of hazardous conditions and how to avoid them but do not provide measurable or comparative means for degrees of risk assessment. Checklists describe most fire prevention inspection formats; again listing many hazardous conditions but also not providing means to determine degree or magnitude of the risks. Schedules, on the other hand, provide lists or grouping of hazardous conditions and provide arithmetic values to each condition based on professional judgement and past experiences; providing a means to achieve some sort of measure of the potential of the hazard. Theoretical methods provide means to evaluate risks or risk elements through more analytical processes of computer simulations, modeling and mathematical linear regressions; growing in popularity through expansion of computer capabilities (Watts, 1992, p.4-89,4-90).

Evaluating the first of the three primary element groups, ignition, is not a simple task in itself. When considering structures and occupancies of all types, the list of ignition or energy sources and the likelihood that a particular and significant source of energy will expose an available and susceptibly ignitable fuel is a complex mixture of events to be considered. Appendix B provides a very sizeable list of energy sources and recognized ignition sources and Appendix C provides a list of fuels and potential fuels that must considered in a the process for evaluation the ignition element.

Narrative, checklists, and schedules rely for the most part on professional judgement and historical data. Consideration of the likelihood of ignition occurring and being sustained to actual fire continuation, based on the brief description previously mentioned, would require a tremendous amount of research and analysis of historical data. To determine the consistent contribution of any one ignition source combining with a single fuel supply and be able to revealing a verifiable condition would be singularly a sizable effort.

Utilization of probabilistic techniques would be the most likely technique to achieve the correlation of data with some amount of verifiable conclusions. The greatest problem with this approach is that all occupancy conditions and potential ignition sources have not necessarily generated data adequate to handle all occupancy and within occupancy scenarios that could even confront Brighton Fire. Ramachandran, (*Fire Technology*, 1988, p.205) indicates that "without carrying out costly surveys, it is difficult to estimate directly the probability due to a particular cause in a particular part" (referring to part of an occupancy). The new Australian Fire Engineering Guidelines (1996), concludes that "there are at present no quantitative methods available for the prediction of potential for ignition (p.8-3)."

Evaluation of the second primary element of risk analysis, fire development and exposure pathways, is no less complicated than the ignition element. Fire growth or development is highly dependent on complex interactions between fuel characteristics, aerodynamic processes involving heat dispersion and losses, and chemical processes of fire and fuels. Quintiere (1997) indicates "fire growth depends on the ignition process; flame spread, which defines it perimeters;

and the mass burning flux over the area involved (p.121)." *The National Fire Risk Assessment Research Project Final Report* (1990) notes that information related to the room of origin and its characteristics play an important role in the fire growth. Area characteristic might include window and door sizes, wall and ceiling construction, as well as the size and dimensional relationships of the room itself (p.I-12, I-16). The Australian <u>Fire Engineering Guidelines</u> indicates that spread beyond the room of origin can be attributed to closures being left open, opening created by glass breakage, construction failures at penetrations of building services, and actual failure of the integrity of the building construction; walls, ceilings, doors, and floors, or even building collapse.

Quintiere (1997) contends that flame spread in itself is a fire phenomenon that is not easily analyzed mathematically (p.97). Fire spread is highly dependent on "the fuel, its orientation, the wind, direction of spread, and other factors (p.99)." Quintiere (1992) in a chapter contribution to <u>Handbook of Fire Protection Engineering</u>, further contends that little information is available for general application of flame spread considerations do to three factors; one, inadequate knowledge is available to make predictions in general applications; two, generally acceptable tests are not available to generate adequate fuel data; three, the multitude of fuel configurations present an impossible totally testable situation (p.1-360).

Harmathy, (*Fire Technology,* 1976) contends that the burning rate and the heat flux is highly ventilation controlled. The ventilation rate determines, to a large extent the duration of the fire and its ability to penetrate room construction; poorly ventilated fire are the most destructive. Harmathy further concludes that "compartment fires are extremely complex processes involving, in addition to hundreds of identifiable variables, a host of incidental variables, (p.97)." As can be imagined, ventilation rates determined by the door or window being open or the early failure of the glass or building construction all create that "host of incidental variables."

Exposure of other portions of the fire building and adjacent structures is another portion of the second primary element of fire risk analysis. The Australian <u>Fire Engineering Guidelines</u> lists conditions of physical and constructional separation as well as distances of separation as primary considerations in this phase of evaluation. But again, determination and repeatability are significantly hampered by lack of data and predictive research which plague an accurate and verifiable means to evaluate these scenarios (p. 10-12, 10-13).

Analysis of the consequences of fire risk presents the largest area of consideration. As Rowe (1980) indicates, this step must define the possibilities or probabilities of the consequences based on the fire growth and development and the value impacts of the consequences; specifically on life and property. These outcomes must consider if early warning systems, protective, containment, extinguishing systems, and response systems have or have not been effective. Finally, consequences must consider tangent evaluations of whether these systems have a cost impact greater than the potential for total loss and potential value of insurance or restoration loans (p.9,10,11).

Roux (1982) relates consequences to the potential for harm. Roux contends that harm comes from the products of fire; heat, smoke, flame, toxic gases are examples sighted. The measure of harm, Roux continues is the amount of loss or cost per exposure. Roux suggests that the measure of success and goal of the Safety Concept Tree is to prevent people from ever being exposed to the noted examples of harm (p.23,24).

Bukowski (1997) indicates that fire exposure to people can be evaluated by application of combustion and toxicology models. These models obviously must consider the person(s) non-mobile and relative to the compartment in which the person is located at the time of extreme exposure (p.11-74).

Kersken-Bradley (1992) indicates that suppression actions by fire fighting agencies, suppression systems, or persons at the site have had little modeling efforts applied to them. Consideration for time of action, type of action, effectiveness of the actions have not been adequately applied. Utilization of probability analysis methods could be effective but the quality and quantity of data directly related to these suppression considerations are not available (p.4-4,4-5). The Australian Fire Engineering Guidelines indicate that the evaluation of public response forces, in their role of consequence evaluation, must include considerations of response time of the forces, time for set-up, time to complete evacuation completeness, time to establish the fire attack, fire control time. All of these elements are obviously coincidental only to the agency that will be responding and must be based on either historical data analysis or actual testing to the best adequacy that can be established. Additionally, many time factors will be determined by building occupation, fire advancement, building accessibility, and many other factors (p.13-1 through 13-9).

"The increasing complexity of buildings regarding, functions, size and configurations, requires a broader attention to the planning of means of escape to ensure the evacuation of buildings in an emergency (Kendik, 1986, p.293)." Kendik indicates that a model (name unknown) was recently developed to make such decisions. Information indicates that the model may have significant value in determining escape capabilities when applied to a consequence evaluation.

The Australian Fire Engineering Guidelines indicate that the evaluation of an evacuation notification system and its impact on the consequences of fire is only truly determined through actual testing; though calculation methods, based on historical information, are covered in the guidelines. The system must be evaluated by clarity of information conveyed, effective notification, as well as the actual the responsiveness of the test group. These tests can only be truly determined effective when applied to the building in which they are intended (p.12-6,7,8).

PROCEDURES

Definition of Terms

Flame Spread. The process of advancing the fire front inair, along surfaces, or through porous materials (Quintiere, 1997, p.252)

Mass Burning Flux. Burning rate per unit area. Flux pertains to heat flow rate per unit area (Quintiere, 1997, p.252, 253).

Risk Assessment Tool. A means, guideline, checklist, or schedule to perform or guide the performance of a fire risk assessment within a building or occupancy.

Research Methodology. The purpose of this research was to evaluate the extent or depth of analysis needed in an assessment process, the values or elements that should be considered in the assessment, and the amount of effort that such an assessment could or should demand.

The research was historical in that a literature review was conducted to understand the present knowledge and technical developments pertaining to fire risk assessment, the elements that should be evaluated in the assessment and the impact on a fire service agency in making risk assessment at the level of technology now available.

The research is action in nature as the majority of the information generated can and will likely be directly applied to an actual risk assessment tool to be applied to evaluating occupancy fire risks within the Brighton Fire Protection District. Many of the specific ignition causes and fuels that can be ignited, determined in the historical research and noted in Appendix A and B, will provide a significant and directly applicable list of elemental components to be considered in the actual development of the assessment tool.

Assumptions and Limitations

It was determined in the research that several computer models have been or are being developed to aid in such fire analysis related areas as smoke spread, fire spread, and comparative analysis of life safety considerations. It is beyond the scope of this research to review each of these models for their actual applicability to fire risk assessment processes. It is assumed that once the actual development of an assessment tool is begun and should the quantitative approach to that assessment tool be selected, that review of these models will be essential.

Sub-elements, noted as part of the NFPA "Safety Concept Tree" and other potential guides for fire risk assessment were also not part of the scope of this research. Appendix B, dealing with energy and ignition sources, Appendix C, dealing with fuel sources, and Appendix D indicate results of research to evaluate the magnitude of the potential impact that could be anticipated in assembling an all inclusive and quantitative assessment tool. These Appendices were included to aid in understanding the significance of data that must be considered in such a tool. The final assembly of a tool obviously would have to include analysis of all sub-elements potentially applicable to fire risk assessment.

RESULTS

Research Question Answers

Research Question 1. Should an exacting, quantitative fire risk analysis method be utilized to evaluate fire hazards presented by structure and facilities? In light of the complicacy and impact of the effort on the resources of the Brighton Fire District and most other fire service organizations to complete a quantitative type assessment process, the concluded answer to this questions is - no. Because the question begins with the word "should", the question is asked in an effort to evaluate the value of the information developed in there search as a means to accomplish the need of the Brighton Fire Protection District and the fire service as an entity to readily determine risk demands versus suppression force capability.

Research has indicated that the conclusions drawn from a qualitative process of assessment could yield the information necessary to compare fire force capability with the demands presented by the possible, or with enough evaluation, probable fire that could occur within a single occupancy.

Harmathy (1976) indicated that compartment fires are complicated processes involving hundreds of identifiable variables and an equal number of incidental variables (p.97). The research has revealed the magnitude of elements to be evaluated and the significant number of variables involved in the assessment of each element for each compartment or area within a single occupancy could produce a significant number of labor hours. Completing the assessment of every risk within a fire district containing over 1000 occupancies would be well beyond the work load abilities of the agency regardless of size.

Research Question 2. What elements or values of fire risks must be examined to compile the data necessary to make a quantitative risk analysis? Research revealed a varied list of elements which could be evaluated to compile what the many authors concluded as a quantitative risk assessment. The research appeared to more consistently conclude on three primary areas of evaluation necessary; ignition or the probability for ignition, fire development or exposure pathway, and the impact of the consequences of the fire once developed. Research of the processes necessary to accomplish evaluation of each of these primary areas brought to light many additional sub-elements. The NFPA "Safety Concept Tree" provided the most comprehensive list of sub-elements; approximately 65 in all. The Safety Tree did not continue to the extent considered necessary by Rowe in his explanation of the consequences element; evaluating insurance costs or loan impacts necessary in the aversion of risks. To achieve a risk assessment process, inclusion and analysis of these 65+ sub-elements will be a necessity and many more will likely surface with that effort.

Research Question 3. What amount of effort would be required to make a quantitative risk analysis productive in a structure by structure process? This question was significantly answered in question 1. A review of Appendix A, B, C, and D, and considering the processes necessary to properly analyze all of those variables alone quickly provides a relative impact view of the needed total process. An attempt was made to achieve a relative man hour figure needed to achieve an assessment with the conclusion that a complex occupancy could reach the mid to high three digit range easily.

DISCUSSION

Had the first research question asked "Could an exacting, quantitative fire risk analysis method be utilized to evaluate fire hazards presented by structures and facilities?", the likely answer would have been - yes. Many of the researched documents readily indicate that the technology is available to make that type of an assessment. Through lengthy and detailed inspections utilizing checklists or narrative guidelines combined with lengthy probability calculations, the likelihood of ignition could have been evaluated. With extensive computer modeling, evaluation of all the possible means for the fire to develop and advance through the building could be completed. The usage of some reported computer models or schedules replicated and expanded from the existing insurance schedules could provide the analysis of the fire consequences.

For the Brighton Fire Protection District to make the make the described assessment of the 1200+ commercial and industrial occupancies within the District would be beyond the capability of the district staff. Much of the literature reviewed indicated that the task was complicated and presented a significant amount of effort. This same literature, however, supported the value that could be gained in not only being able to analyze the impact of a fire scenario but improve life safety considerations within the occupancy at the same time.

Much of the information developed relating to the fact that such an analysis can be accomplish has been validated through the number of concurring documents. To require such an assessment of newly designed building by the designing engineers or fire protection engineers is not beyond their capabilities. This maybe the real answer for the future. Additionally, the research has revealed a host of items or facts about building which will be valuable in any approach to hazard or risk assessment and the gathering of that information can begin now.

With the elements of fire risk assessment being more completely identified, the ability to complete far more detailed and complete fire prevention inspections on a daily basis has been created as well. The primary and sub-elements can be used to create far better inspection checklists and develop the needed training to support the checklist usage. These same primary and sub-elements can be utilized to develop improve construction plan review processes which should produce a greater insight into potential life safety dangers not before focused on. One additional usage could be in the development of fire response preplan development. With these expanded lists of building considerations, fire response rescue and fire suppression operations plans can be developed to consider a greater number of rescue and suppression potential problems.

RECOMMENDATIONS

The more readily available secondary results of the research can be incorporated fairly easily into the daily operations of the Brighton Fire District. Improved inspection quality, more in-depth plan review efforts, and improved operational preplanning will all have significant value. Training, utilizing the concepts identified within this research and the actual detailed elements of fire risk, should be instituted within the prevention area of the district staff immediately with expansion to operational forces in the future.

The need to be able to determine the proper suppression staff levels of capability still exists. A means of utilizing what has been developed within this research through another process of accomplishing the risk assessment must be developed.

Consideration should be given to a qualitative approach, which relies less on a mathematics and more on comparison, to seek a process with much less impact but could achieve a fairly accurate risk level determination for comparison. Regardless of the approach to assessment, the gathering of a great deal of valuable information which will be utilized in any assessment process can begin today. This information can become an integral part of the occupancy data file for each and every occupancy, maintained with each fire prevention inspection cycle. Once the appropriate assessment process has been developed, the information will have been maintained current and applicable.

In a 1989 Fire Engineering periodical article, Francis Brannigan likened loss control to a gambling slot machine. With each of the three wheels indicating a separate element of loss control; one being fire cause, the second being fire extension, and the third being problem management. The gambler's objective is to get all of the wheels to come-up jackpot at the same time. But in the case of loss control, all three wheels indicating jackpot, means disaster (p.48). Until the ability to readily achieve quantifiable analysis of all the key elements of fire risk assessment is developed, the most important effort of any fire department is to work diligently to prevent the slot machine jackpot through careful daily inspection record keeping of all the sub-elements of fire risk occupancy in an effort to prevent the elements from coming together in the worst case scenario.

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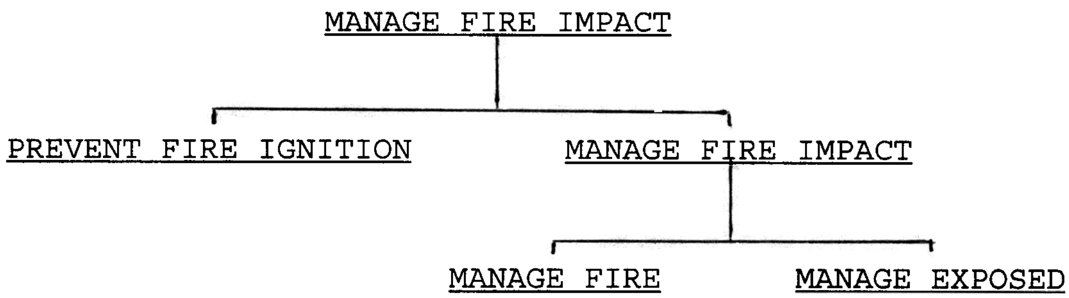
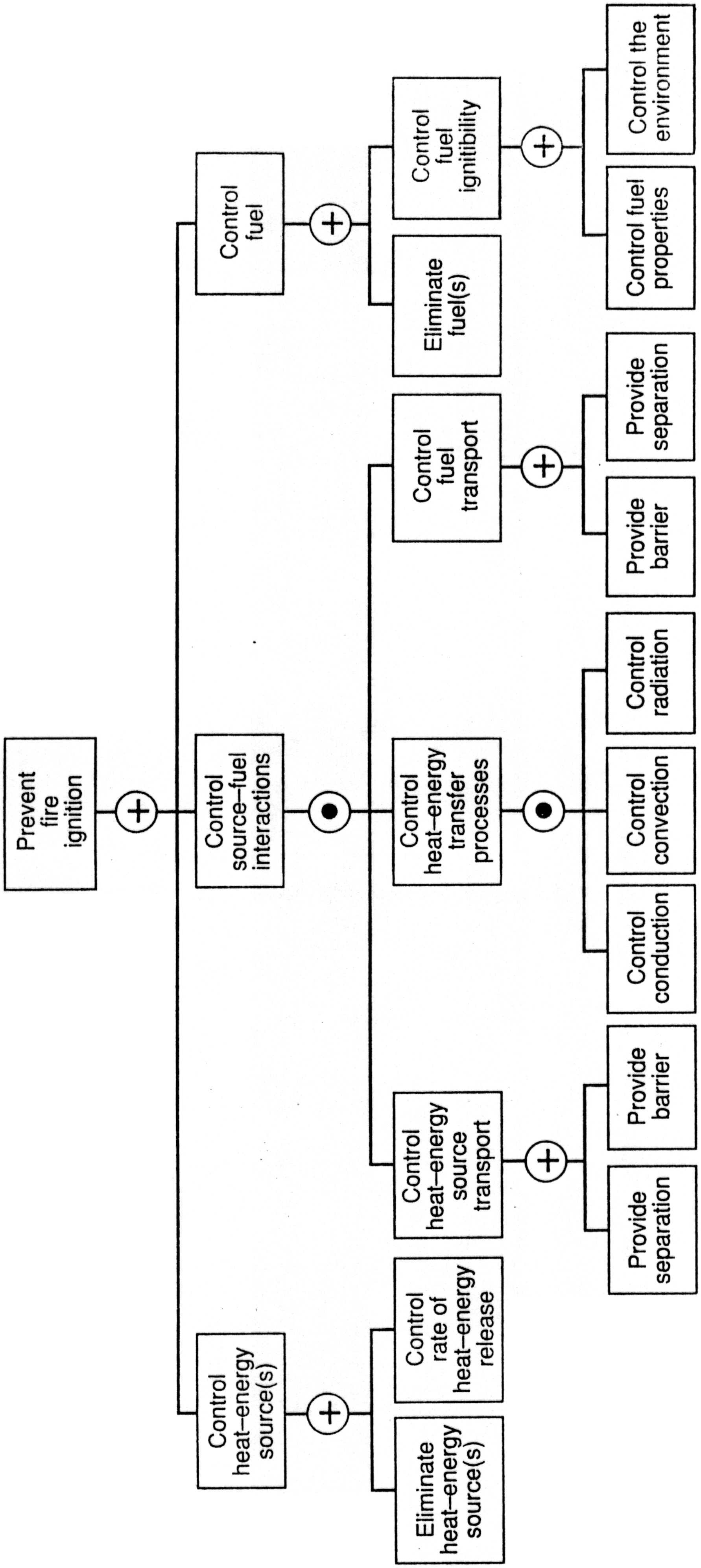
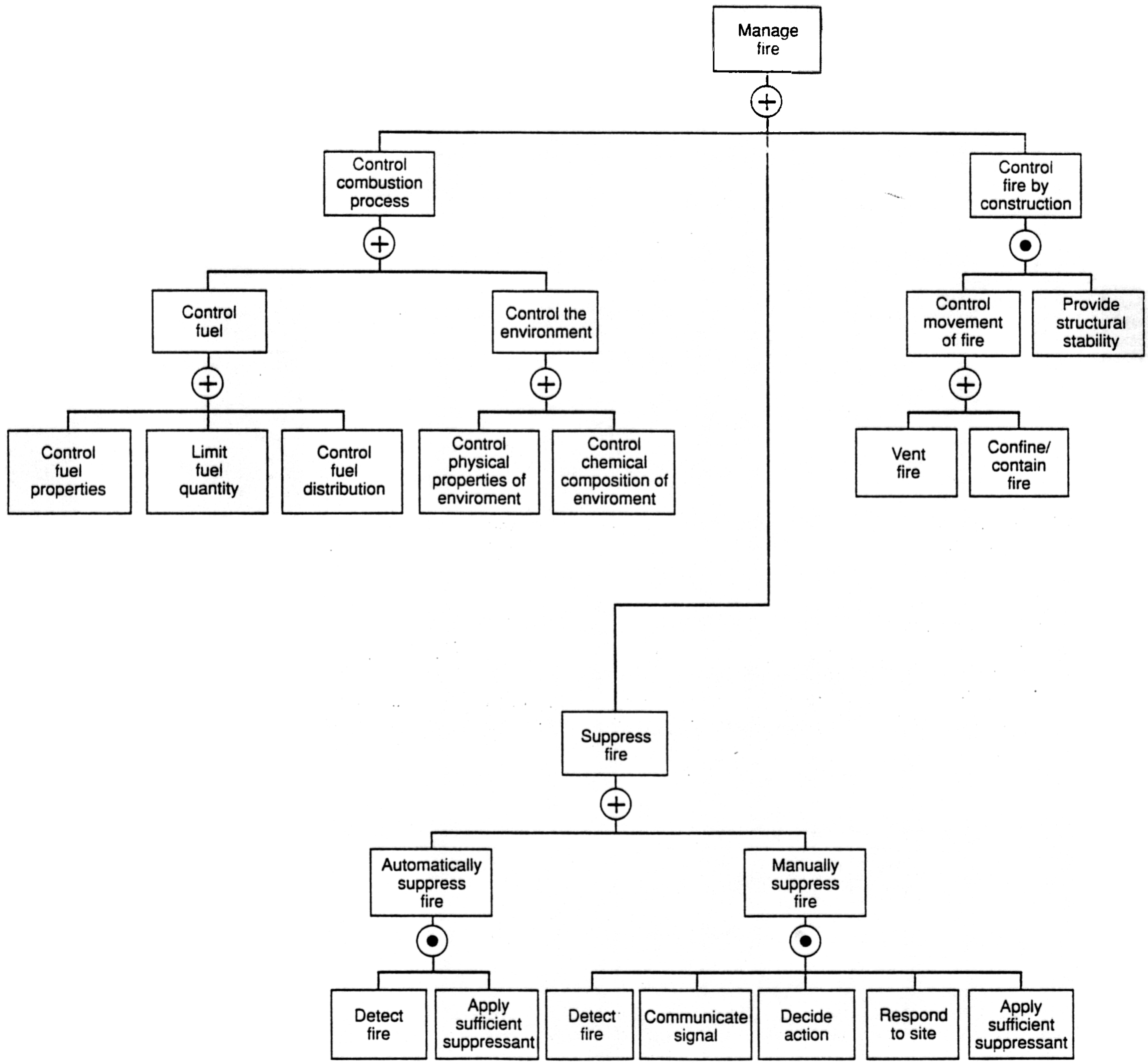
APPENDIX A

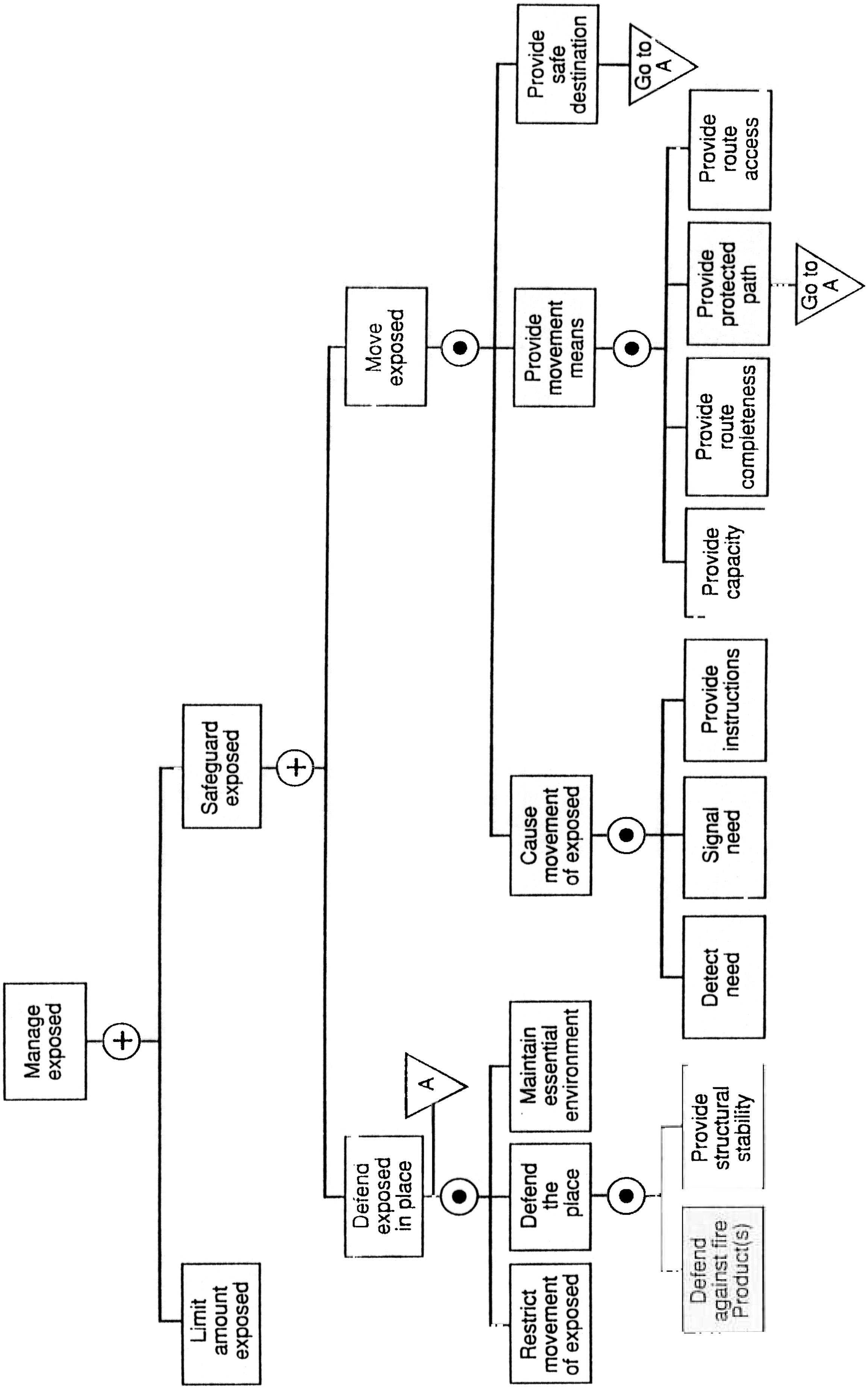
FIRE SAFETY CONCEPTS TREE



(NFPA, 1995, pp.4,5,6,7


Prevent fire ignition
Control heat-energy source(s)
Control source-fuel interactions
Control fuel
Eliminate heat-energy source(s)
Control rate of heat-energy release
Control heat-energy source transport
Control heat-energy transfer processes
Control fuel transport
Eliminate fuel(s)
Control fuel ignitibility
Provide separation
Provide barrier
Control conduction
Control convection
Control radiation
Provide barrier
Provide separation
Control fuel properties
Control the environment


Manage fire
Control combustion process
Control fuel
Control fuel properties
Limit fuel quantity
Control fuel distribution
Control the environment
Control physical properties of enviroment
Control chemical composition of enviroment
Control fire by construction
Control movement of fire
Vent fire
Confine/ contain fire
Provide structural stability
Suppress fire
Automatically suppress fire
Detect fire
Apply sufficient suppressant
Manually suppress fire
Detect fire
Communicate signal
Decide action
Respond to site
Apply sufficient suppressant



Manage exposed
Limit amount exposed
Safeguard exposed
Defend exposed in place
Move exposed
A
Restrict movement of exposed
Defend the place
Maintain essential environment
Defend against fire Product(s)
Provide structural stability
Cause movement of exposed
Provide movement means
Provide safe destination
Go to A
Detect need
Signal need
Provide instructions
Provide capacity
Provide route completeness
Provide protected path
Go to A
Provide route access

National Fire Protection Association, *Standard Classification for Incident Reporting and Fire Protection Data* (1995, pp.901-54 - 901-55).

Classifications:

- Heat, Sparks, Embers, or Flame from Outside, Open Fires.
  - Contains 7 sub-categories
    - Example: outside open fire for warming
- Heat from Fuel-Fired or Fuel-Powered Equipment (gas or liquid fuel).
  - Contains 9 sub-categories
    - Example: Heat from natural gas fueled equipment other than torch
- Heat from Fuel-Fired or Fuel Powered Equipment (solid fuel)
  - Contains 10 sub-categories
    - Example: Heat from wood, paper, fueled equipment.
- Heat from Electrical Equipment Arcing or Overloaded.
  - Contains 10 sub-categories
    - Example: Short-circuit arc from mechanical damage.
- Heat from Hot Object.
  - Contains 10 sub-categories
    - Example: Electric lamp. Included are light bulbs.
- Heat from Explosives or Fireworks.
  - Contains 8 sub-categories
    - Example: Munitions.
- Heat from Other Open Flame, Sparks, or Smoking Material.
  - Contains 10 sub-categories
    - Example: Match, lighter
- Heat from Natural Sources.
  - Contains 6 sub-categories
    - Example: Lightning discharge
- Heat from Spreading from Another Unwanted or Hostile Fire (Exposure)
  - Contains 6 sub-categories
    - Example: Conducted heat
- Other Form of Heat of Ignition
  - Contains 3 extremely general sub-categories
    - Example: Multiple forms of heat of ignition

Specific Examples of Ignition Sources

Electrical: General categories of ignition sources

1. electrical failure: short circuits, ground faults
2. improper installations: overloading, equipment damage
3. lack of maintenance: deterioration of insulation
4. improper use: not used in the proper environment

5. carelessness or oversight: failure to turn off

Between 1989 and 1993, over 85,510 fires were reported by fire departments with the ignition source of an electrical nature. The largest sources were of 40,000 involving all conditions of failure of electrical distribution systems and equipment.
(Source: Caloggero, 1997, pp.3-5 - 3-10).

Heating Systems & Appliances: General categories of ignition sources
1. liquid and gas fueled equipment: poor maintenance, failure of air induction means
2. solid fueled equipment: over-firing (too high of temp.) careless handling of ashes
3. room or space heaters: improper placement, miss fueling

Between 1983 and 1993, the space heater incidents were reduced by 50% with information and education.
(Source: Johnson, 1997, pp.3-75 - 3-79).

Manufacturing Processes: General categories of operations and source examples
1. metalworking: spontaneous combustion of cuttings, combustion of coolant/lubricants, metal reactions,
2. welding & cutting: poor maintenance of oxygen equipment, sparks, oil soaked materials in area
3. woodworking: vaporization of resins, dusts, improper abrasive materials and heat building up
4. spray finishing and powder coating: atomization of flammable materials, electrostatic charge development
5. dipping and coating: exposed flammable liquids, multiple minor ignition sources in area
6. housekeeping: smoking control, storage of cleaning materials and equipment, oil soaked rags
(Sources: Dobbs, Manz, Cholin, Scarbrough, Sheppard Higgins, 1997, Chapter 3).

Example Ignition Sources by Type of Occupancy

Assembly Occupancies:
* 1. cooking: improper vapor removal,
2. candles and other open flames: improper containment devices
3. stages: lighting, scenery
4. projection booths: electric arc, hazardous dust exposures

* 5. incendiary
(Source: Sharry, 1997, p.9-24)

Special Structures and High-Rise:
* 1. electrical: complication of distribution, overloading
2. sources consistent with occupancy type
3. heating: special requirements may create unusual conditions
(Source: Caldwell, 1997, p.9-15)

Merchantile:
1. electrical
2. heating
3. special processes involved: jewelry - gas torches,
* 4. incendiary
(Source: Schultz, 1997, p.9-27)

Businesses:
1. electrical distribution
2. heating appliances,
3. smoking
* 4. incendiary
(Source: Bathurst, 1997, p.9-33 -9-35)

Educational:
1. similar to business occupancies
2. electrical distribution
* 3. incendiary
(Source: Stashak, 1997, p.9-38)

Detention or Correctional:
1. vocational shop activities: welding, cutting, metalworking
* 2. incendiary
(Source: Carson, 1997, p.9-42,9-43)

Health Care:
1. special equipment consistent with these operations
2. appliances
3. smoking
(Source: Jaegar, 1997, p.9-50)

Board and Care:
1. smoking materials
2. heating appliances
3. electrical equipment
(Source: Lathrop, 1997, p.9-43)

Hotels:
1. smoking
* 2. incendiary
(Source: Bell, 1997, p.9-64)

Apartment Buildings:
1. smoking
2. incendiary
3. portable heating
4. child play

(Source: Bush, 1997, p.9-67,9-68)

Lodging or Rooming Houses:
1. smoking
2. cooking
3. electrical

(Source: Longhitano & Antonetti, 1997, 9-74,9-75)

Storage:
* 1. incendiary
2. material handling equipment
3. careless handling of open flame equipment
4. portable heating devices

(Source: Hisley, 1997, p.9-84)

Library & Museum Collections
1. arson
2. electrical distribution
3. improper storage adjacent to heating devices
4. heating equipment failure

(Source: McDaniel, 1997, p.9-92)

* Indicates primary cause as noted in <u>Fire in the United States: 1983-1990</u>. (National Fire Data Center, 1993, pp.134-171)

APPENDIX C

FUEL SOURCES

National Fire Protection Association, *Standard Classification for Incident Reporting and Fire Protection Data* (1995, pp.901-56 - 901-59).

Material Identification:

Forms of Materials:

1. Structural Components, Finish
   - Contains 10 Sub-categories
     - Example: interior wall covering
2. Furniture, Utensils
   - Contains 8 Sub-categories
     - Example: cabinetry
3. Soft Goods, Wearing Apparel
   - Contains 10 Sub-categories
     - Example: wearing apparel not on a person.
4. Adronment, Recreational Material
   - Contains 9 Sub-categories
     - Example: toy, game
5. Supplies, Stock
   - Contains 10 Sub-categories
     - Example: rope, cord, twine, yarn
6. Power Transfer Equipment, Fuel
   - Contains 10 Sub-categories
     - Example: pipe, duct, conduit hose
7. General Form
   - Contains 8 Sub-categories
     - Example: fertilizer
8. Special Form
   - Contains 8 Sub-categories
     - Example: chips
9. Other Form of Material
   - Contains 5 Sub-categories
     - Example: Multiple forms of material first ignited

Types of Materials:

1. Wood, Cellulose-Natural Occurring

Contains 9 Sub-categories
Example: wood, grass
2. Gas (not gasoline)
Contains 10 Sub-categories
Example: LP-gas, natural gas
3. Flammable, Combustible Liquid
Contains 10 Sub-categories
Example: gasoline
4. Volatile Solid, Chemical
Contains 10 Sub-categories
Example: radioactive material

5. Plastics
Contains 10 Sub-categories
Example: rigid plastic
6. Natural Product
Contains 10 Sub-categories
Example: leather
7. Wood, Paper
Contains 10 Sub-categories
Example: sawn wood
8. Fabric, Textile, Fur
Contains 10 Sub-categories
Example: wool, wool mixture, finished goods
9. Material Compounded with Oil
Contains 8 Sub-categories
Example: oilcloth
10. Other Type of Material
Contains 8 Sub-categories
Example: animal

Example Fuels by Type of Occupancy

Assembly Occupancy:
1. interior furnishings
2. wall coverings
3. scenery, stage back-drops

(Source: Sharry, 1997, pp.9-22 - 9-25)

Special Structures and High Rise:
1. interior storage, paper
2. interior furnishings
3. multiple types

(Source: Caldwell, 1997, pp.9-14,9-15)

Merchantile:
1. storage of stock
2. advertising materials
3. display materials

(Source: Schultz, 1997, pp.9-28, 9-29)

Businesses:
1. furnishings

2. contents
3. finishes
(Source: Bathurst, 1997, p.9-34)

Educational:

1. clothing, personal effects
2. earthwork
3. teaching supplies
4. vocational supplies

(Source: Stashak, 1997, p.9-39)

Detention and Correctional:

1. clothing, personal affects
2. sleeping equipment and materials
3. finishes

(Source: Carson, 1997, (p.9-45)

Health Care:

1. medical libraries
2. special equipment, x-ray film,
3. bedding equipment, supplies
4. plastics

(Source: Jaegar, 1997, pp.9-50 - 9-52)

Board and Care:

1. personal belongings, furnishings
2. interior finish materials
3. over-stuffed furnishings

(Source: Lathrop, 1997, p.9-61)

Hotels:

1. furnishings
2. laundry room, linens, supplies,
3. finishes

(Source: Bell, 1997, pp.9-64,9-65)

Apartment Buildings:

1. varying qualities of personal belongings
2. building materials
3. finishes

(Source: Bush, 1997, pp.9-67,9-68)

Storage:

1. grain dusts
2. cardboard
3. plastics

(Source: Hisley, 1997, p.9-85)

Manufacturing and Industry

1. cooling and lubrication fluids
2. flammable and combustible gases and liquids
3. oxidizing gases
4. dusts, resins

(Sources: Dobbs, Manz, Cholin, Scarbrough, 1997, Chapter 3)

APPENDIX D

FIRE SPREAD

National Fire Protection Association, *Standard Classification for Incident Reporting and Fire Protection Data*, (1995, pp.901-64 - 901-68)

Factors Contributing to Spread

Building Construction or Design Factors
Contains 54 Sub-categories
Examples: ceiling finish, wall collapse, lack of fire doors, stairwell not enclosed

Acts of Omission
Contains 37 Sub-categories
Examples: vandalism, misuse of equipment, fire doors blocked open

Building Contents
Contains 24 Sub-categories
Examples: dust accumulation, improper storage, furniture, fixtures

Delays
Contains 23 Sub-categories
Examples: detection of fire, system inappropriately shut off, secured area

Protective Equipment
Contains 22 Sub-categories
Examples: pump failure, fire door failure, water supply inadequate

Electrical or Mechanical Equipment

- Contains 12 Sub-categories
  - Examples: friction, rupture, overheating
- Natural Conditions
  - Contains 18 Sub-categories
    - Examples: wind, low humidity, earthquake
- Fireworks
  - Contains 34 Sub-categories
    - Examples: firecracker, military devices

Factors Contributing to Flame Travel

- Interior Finish
  - Contains 8 Sub-categories
    - Examples: combustible ceiling, wall, floor materials
- Structural Factor Allowing Vertical Travel
  - Contains 8 Sub-categories
    - Examples: failure of rated assemblies, air-handling ducts
- Structural Factor Allowing Horizontal Travel
  - Contains 9 Sub-categories
    - Examples: door open, window, wall

- Physical Transfer of Material Ignited
  - Contains 6 Sub-categories
    - Examples: wind, gravity pipeline, animals
- Building Contents
  - Contains 8 Sub-categories
    - Examples: decorations, furniture